Charge Balance Function in relativistic heavy ion collisions with the UrQMD Model

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What is the Balance Function for?

- Variable to describe particle productions in heavy ion collisions in terms of conservation laws.
- The ***charge*** balance function quantifies the correlation between charge and anti-charge particles
  - identifies particle-antiparticle pairs on a statistical basis
  - gives information of charged particle production in space and time

Idea behind the Balance Function

- Charge and anti-charge particle created
  - close together in space and time in heavy ion collision (local charge conservation)
- Early created particle pairs
  - pulled apart by the system's expansion
  - suffer possible scattering effects
  - less correlated at the end of the collision
- Later created particle pairs
  - formed later due to a longer lived deconfined phase?
    (*delayed hadronization* , speech of Pratt: Chemical Evolution of the QGP, 2013)
  - closer to each other and more correlated
  - experience only little system expansion and scattering effects

The Charge Balance Function - Equation

(Phys. Rev. Lett. 85,2689, 2000 Bass, Danielewicz & Pratt)

postulated as:

$$B(p_2|p_1) = \frac{1}{2}(\rho(b,p_2|a,p_1) - \rho(b,p_2|b,p_1) + \rho(a,p_2|b,p_1) - \rho(a,p_2|a,p_1))$$

Conditional probability:

- particle b in rapidity p_2 by the condition of opposite-sign (+-) particle a being in p_1

$$\rho(b,p_2|a,p_1) = \frac{N(b,p_2|a,p_1)}{N(a,p_1)}$$

- particle b in rapiditiy p_1 by the condition of like-sign (++) particle b being in p_2

$$\rho(b,p_2|b,p_1) = \frac{N(b,p_2|b,p_1)}{N(b,p_1)}$$

$$B(\Delta\eta) = \frac{1}{2}\frac{N_{+-}(\Delta\eta) - N_{++}(\Delta\eta))}{N_+} + \frac{N_{-+}(\Delta\eta) - N_{--}(\Delta\eta)}{N_-}$$

The Charge Balance Function - Width

- balance function width is proposed as weighted average:

$$< \Delta\eta >= \frac{\sum_{n=0}^{N} B(\Delta\eta)\Delta\eta}{\sum_{n=0}^{N} B(\Delta\eta)}$$

Narrowing of Balance Function

- proposed significance of the balance function:

  (Phys. Rev. Lett. **90**, 172301, 2003 J. Adams et al. (STAR Collaboration))

  - Narrowing of the balance function
    - indication of delayed hadronization?

  - Broader balance function
    - scattering effects

Expectations of the Balance Function

- Is there centrality dependence?
- Pion pairs : investigate charge balance
- Kaon pairs : investigate strange quark balance
- In peripheral collisions of heavy ions
  - similar balance function to nucleon collisions

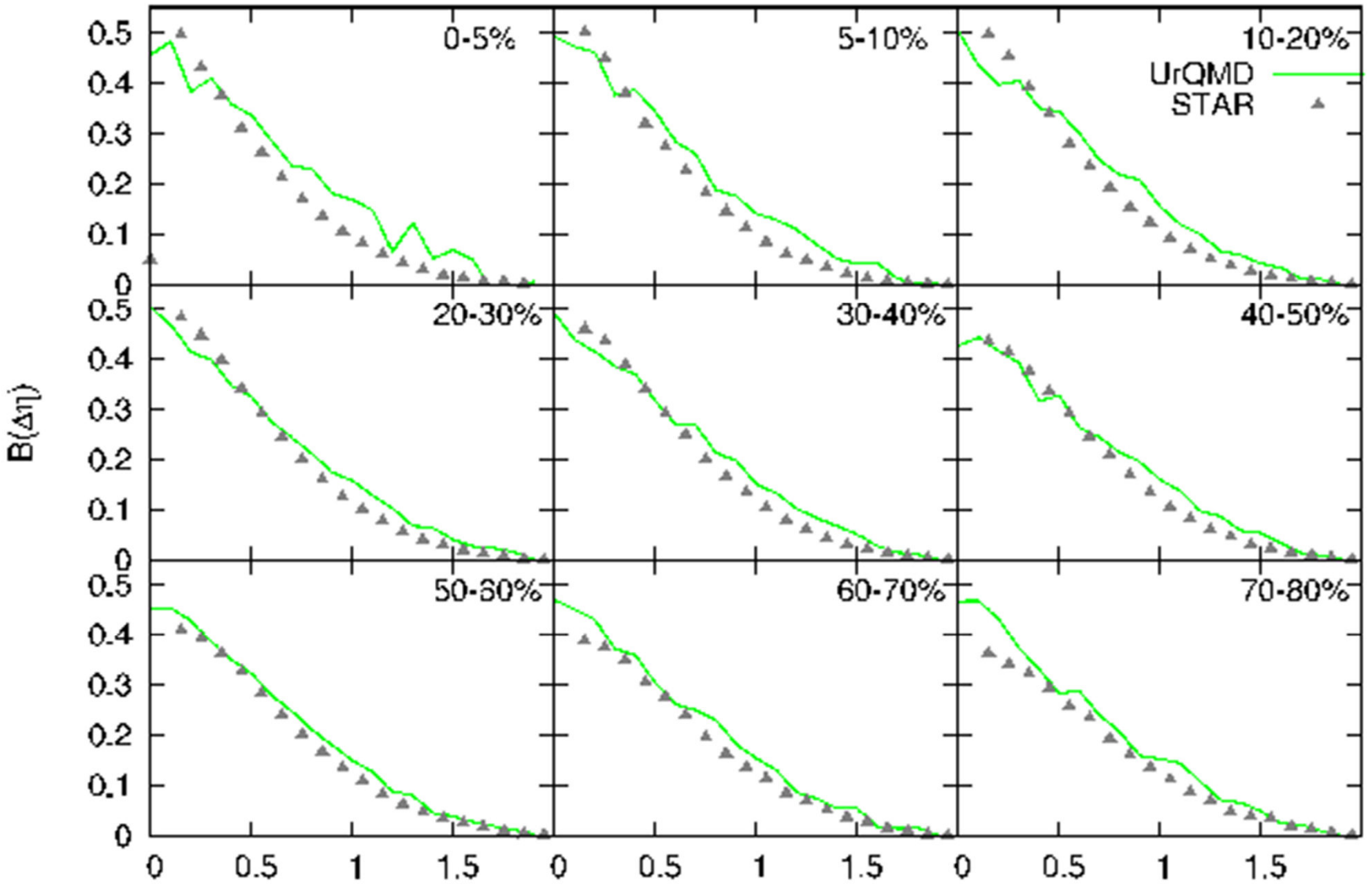
Results : Acceptance

- UrQMD collisions
  - 100.000 events for Au+Au
  - 250.000 events for p+p

- STAR measurements (for comparison)
  - 1 mio events for Au+Au
  - 3 mio events for p+p

Acceptance range for all data in UrQMD and for all measurements at STAR: $|\eta|<0.1$

Balance Function: All Charged Particle Pairs



Au+Au @ 200 GeV

0.2 GeV/c < p_T < 2.0 GeV/c

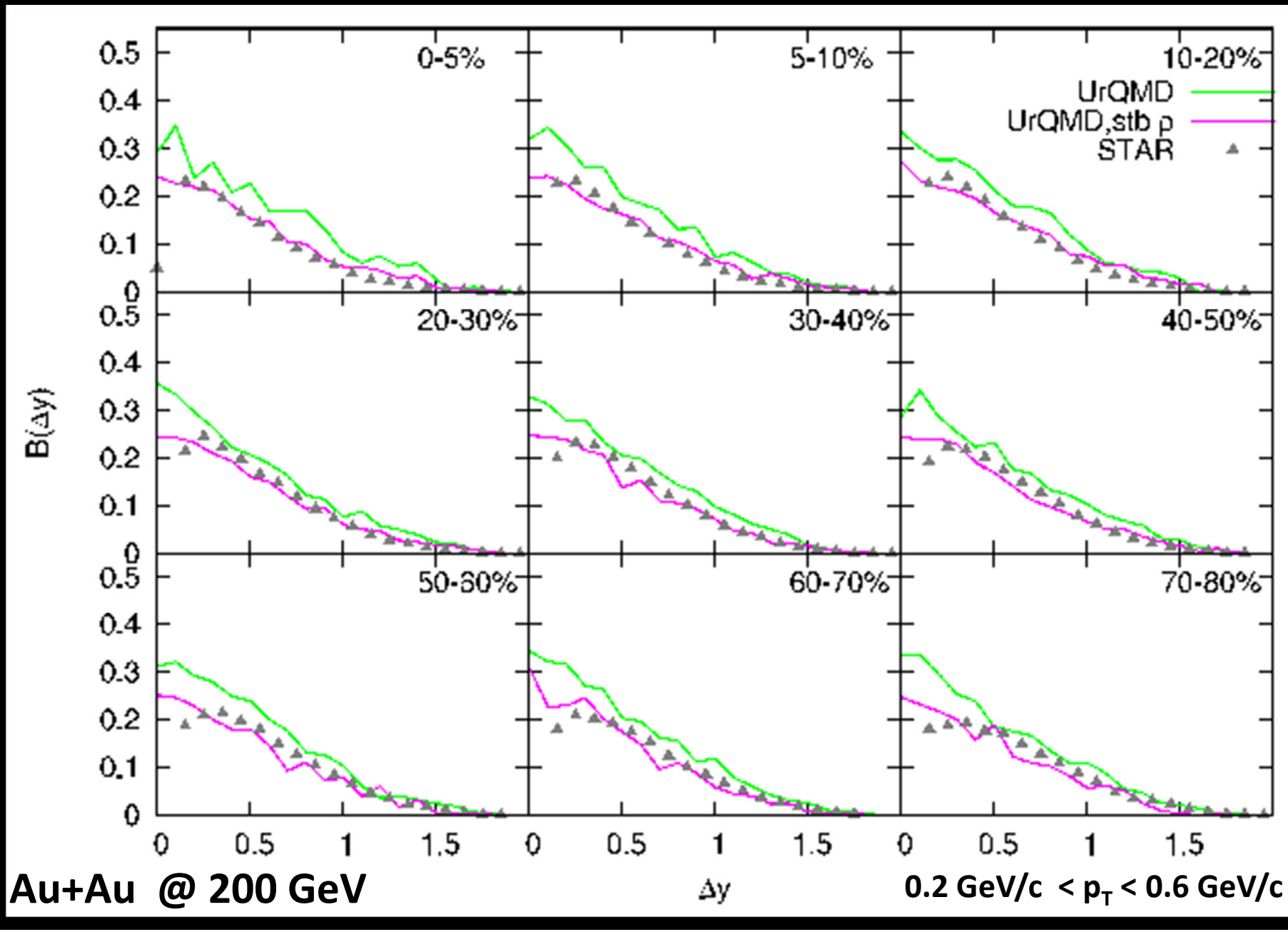
Results of the Balance Function: Charged Pion Pairs

- Acceptance Range:

  0.2 GeV/c $< p_T <$ 0.6 GeV/c

- ρ decays 100% into charged pions
  - ρ particles decay late in the collision on average
  - What if we keep the ρ stable in the collision?

Balance Function: Charged Pion Pairs



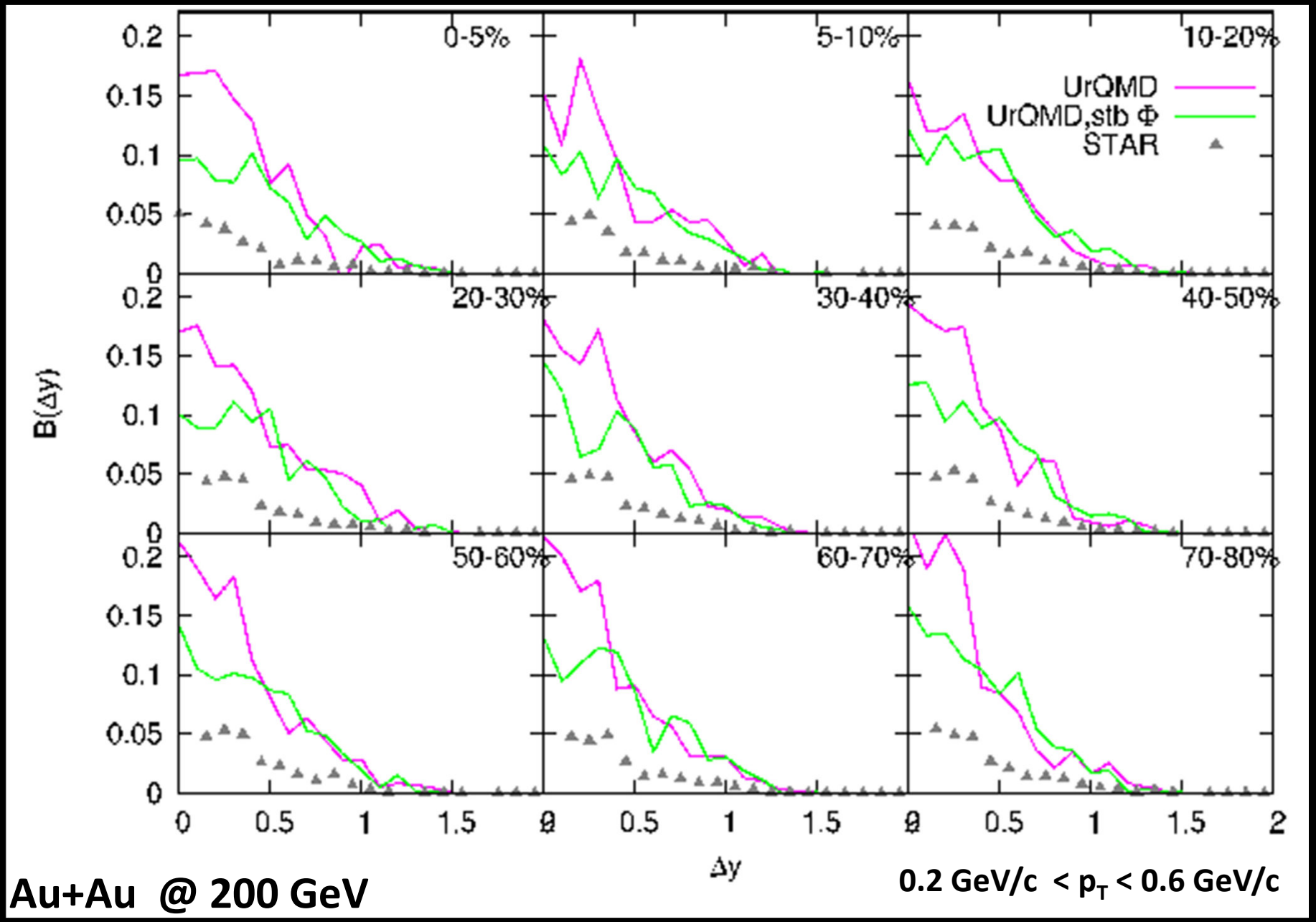
Results of the Balance Function: Charged Kaon Pairs

- Acceptance Range:

  $0.2\ \text{GeV/c} < p_T < 0.6\ \text{GeV/c}$

- ϕ decays into charged Kaons
  - What if we keep the ϕ particle stable?

Balance Function: Charged Kaon Pairs

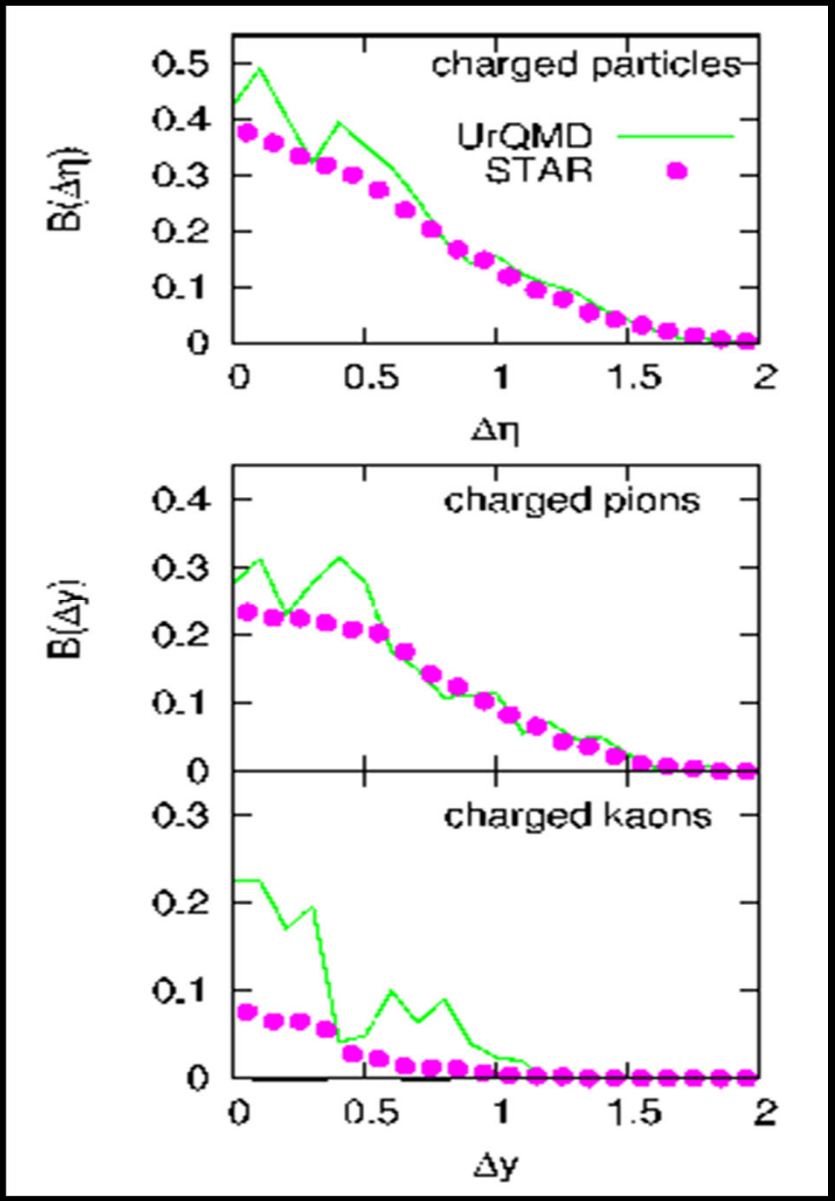


Au+Au @ 200 GeV

0.2 GeV/c < p_T < 0.6 GeV/c

Balance Function Comparison

p+p



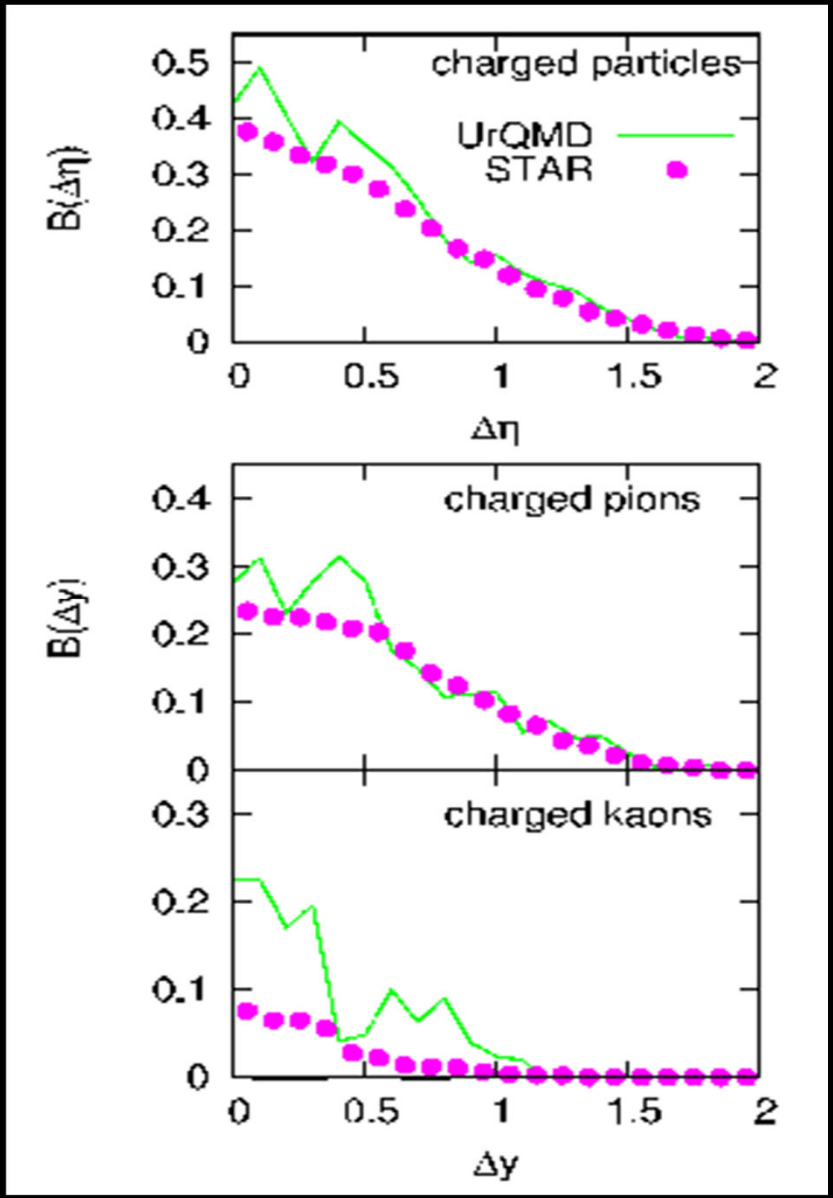
@ 200 GeV

- only two nucleons involved in collision

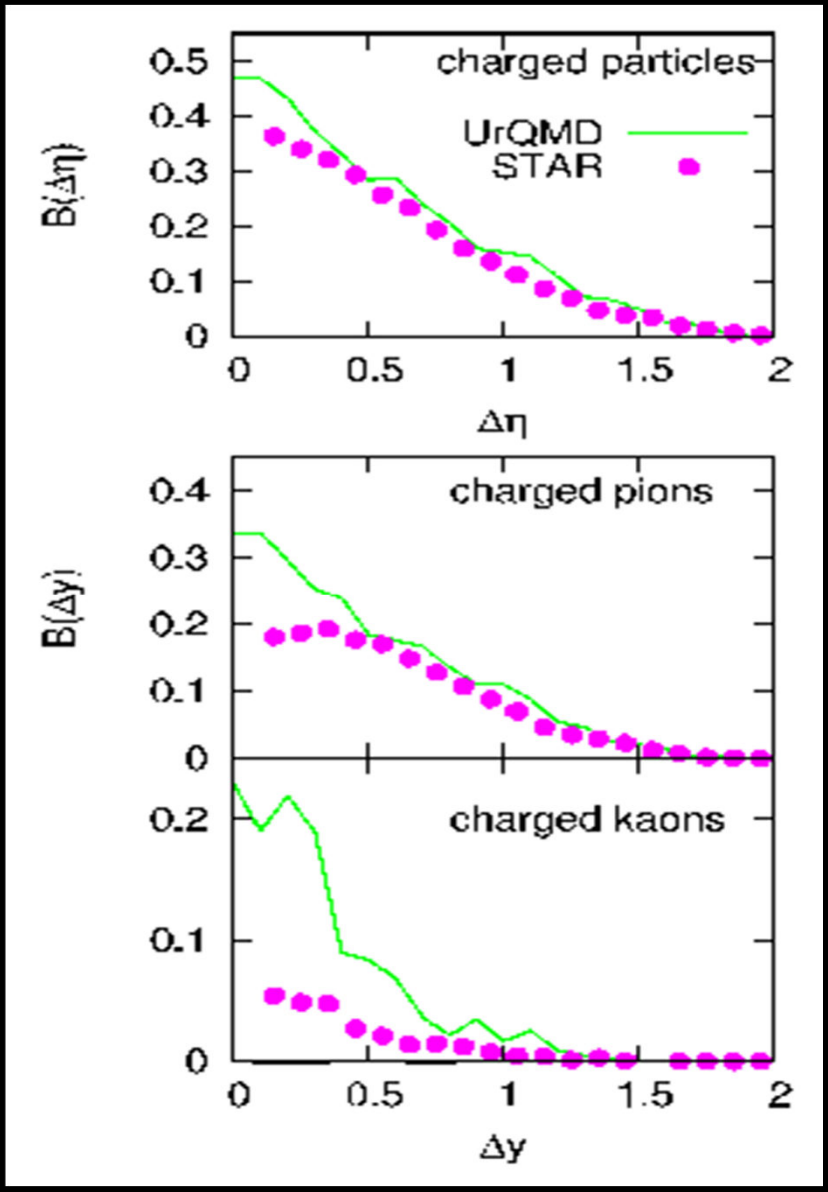
- comparison with most periphal collision of a heavier ion? (few participating particles)

Balance Function Comparison

p+p



Au+Au 70-80% centrality

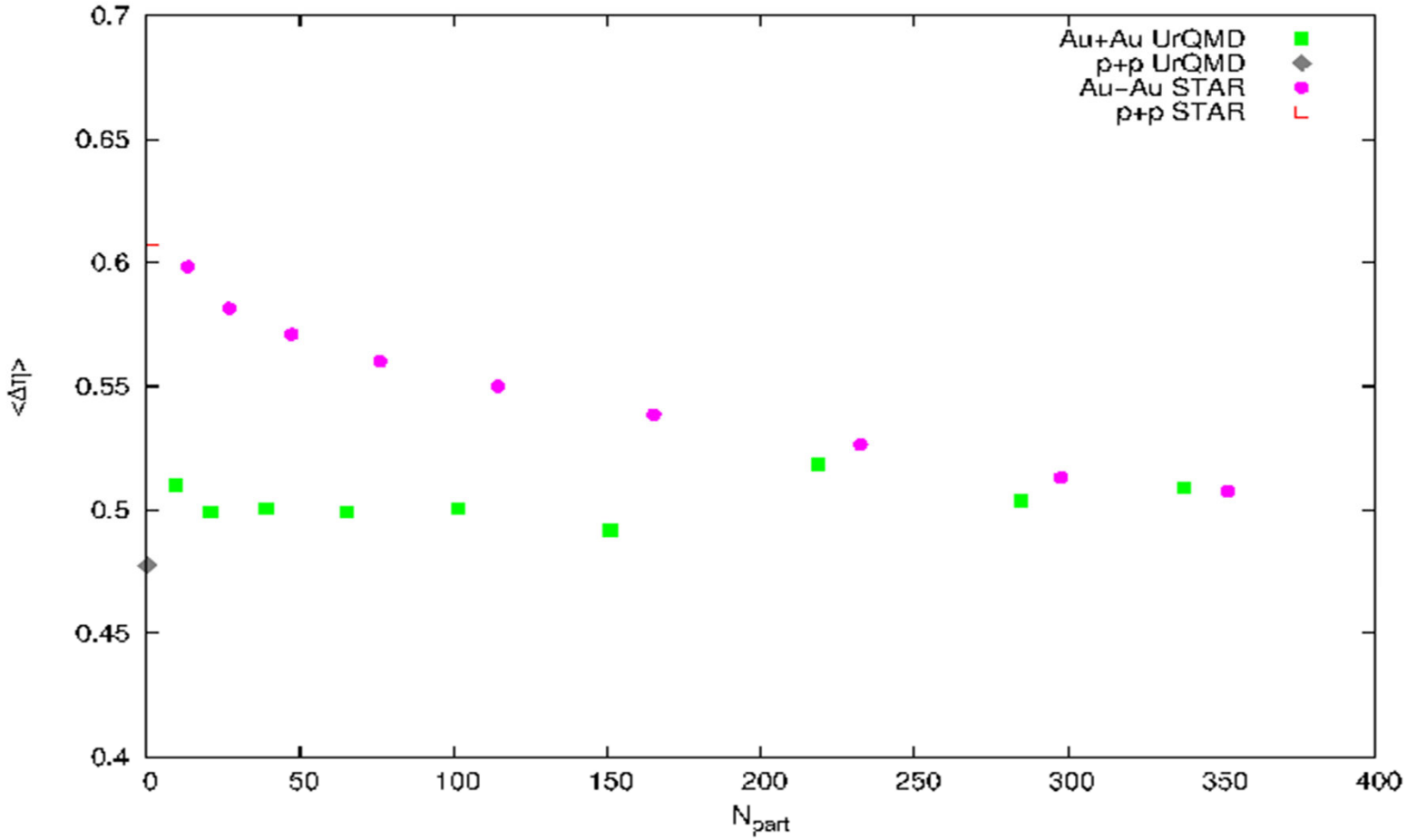


Results of the Balance Function Width

- Comparison of balance function width of p+p and Au+Au collisions with UrQMD and STAR.

- The width as weighted average has been determined for:
  - All charged particles $0.1 < \Delta\eta < 2.0$
  - Charged Pions and charged Kaons $0.2 < \Delta y < 2.0$

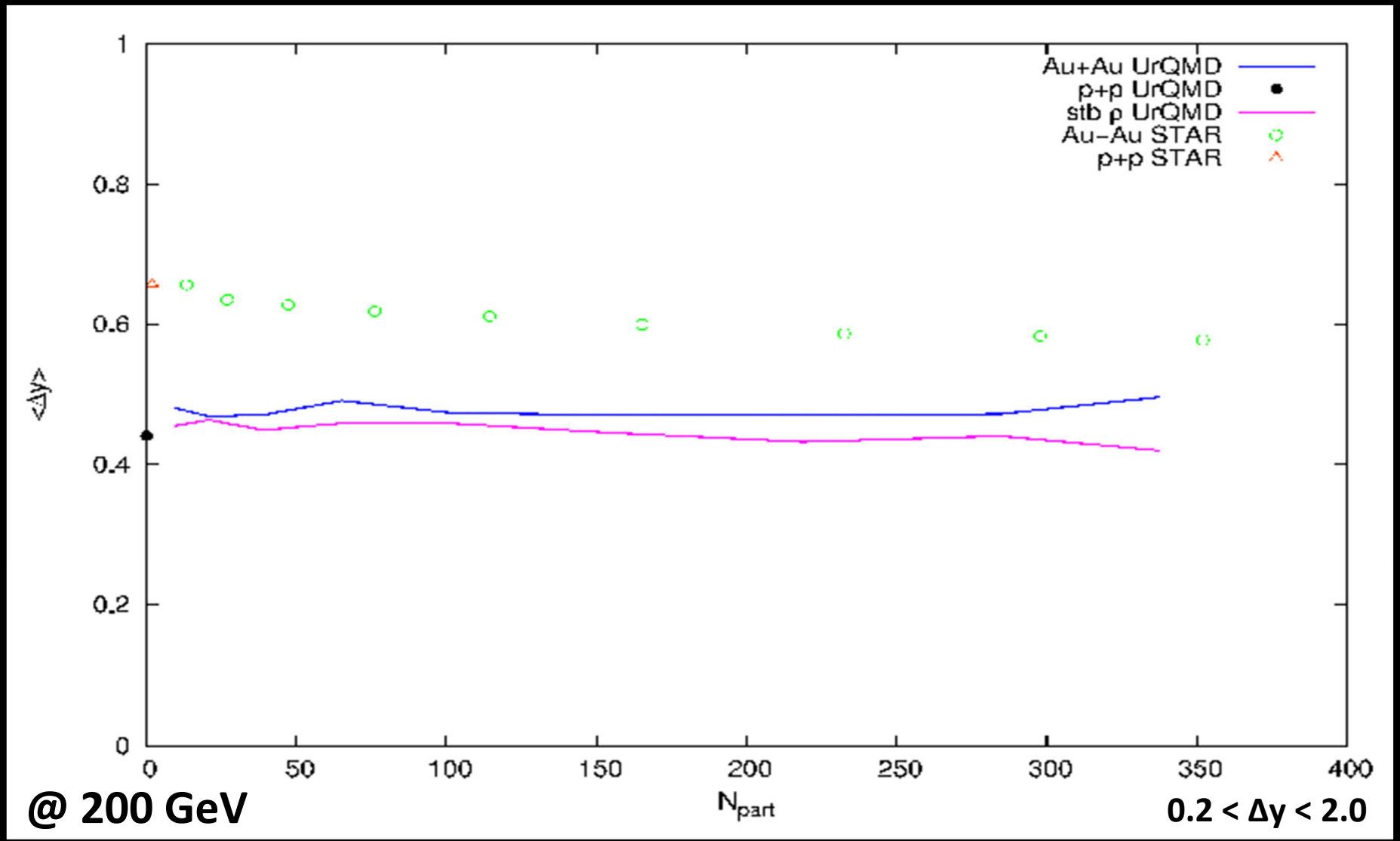
Results of the Balance Function Width: All Charged Particle Pairs



@ 200 GeV

0.1 < Δη < 2.0

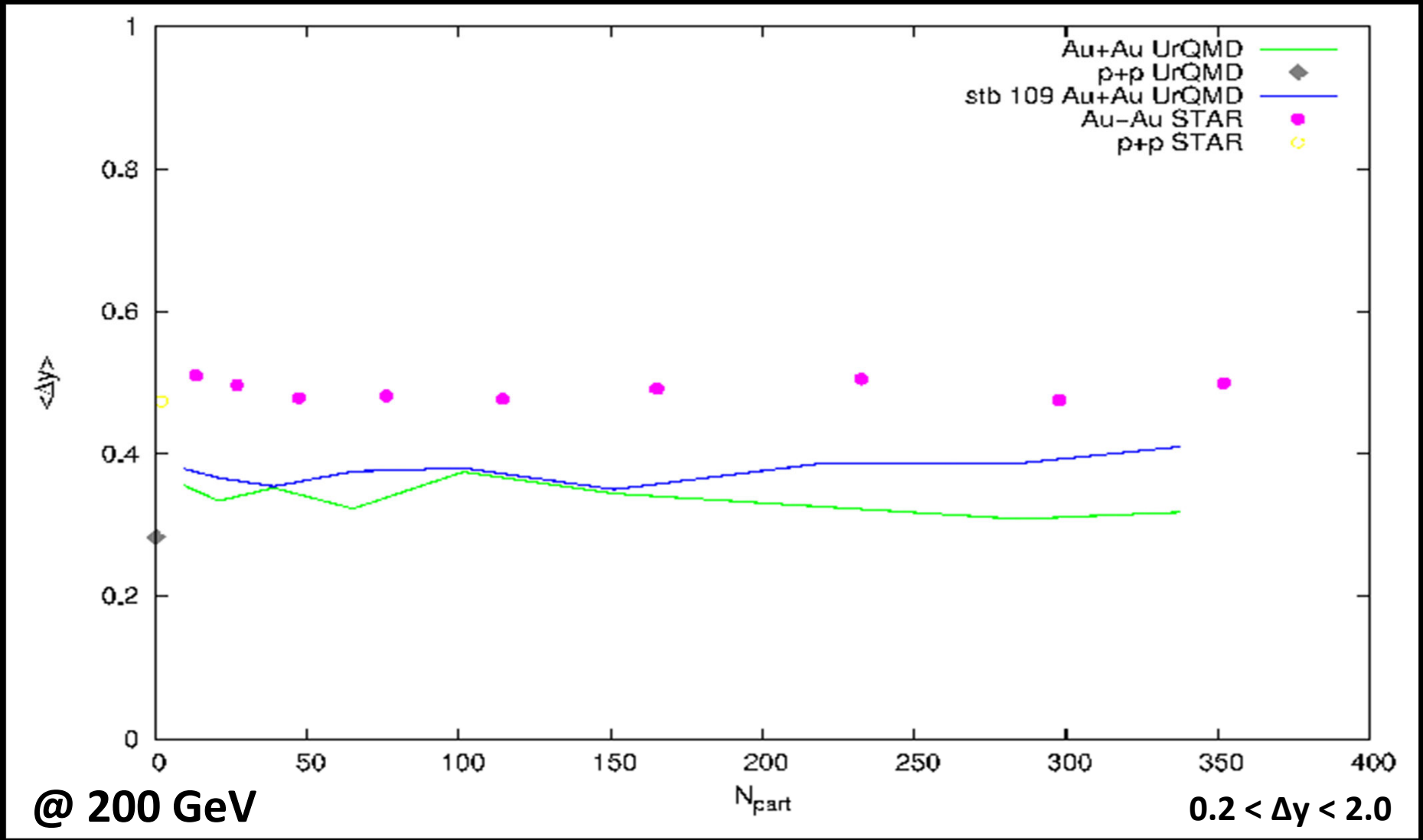
Balance Function Width: Charged Pion pairs



@ 200 GeV

0.2 < Δy < 2.0

Balance Function Width: Charged Kaon pairs



@ 200 GeV

0.2 < Δy < 2.0

Conclusions

- UrQMD shows no centrality dependence in the balance function width
- Charged Pion pairs are produced in ρ decays mainly at the end of the collision
- Charged Kaon pairs are produced when ϕ decays at the end of the collision ($\Delta y<0.4$)
- Balance function narrowing
  - No signs for delayed hadronization
  - Influenced by resonance decays (ρ,ϕ) and scattering
- The Au+Au peripheral collision and the p+p collision are consistent